

Research article

Scapular contribution for the end-range of shoulder axial rotation in overhead athletes

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Abstract

The aim of this study was to analyze the relative contribution of the scapular motion on the extreme range-of-motion of shoulder external and internal rotation, in overhead athletes. An electromagnetic tracking device (Flock of Birds) was used to record humeral and scapular kinematics. The dominant arm of 26 male subjects (13 athletes and 13 non-athletes) was studied while subjects actively reached end-range of internal and external rotation. Humeral and scapular angles were calculated and compared across groups by means of a t-test for independent samples. A bivariate correlation approach was used to describe the relationship between humeral angles and scapular variables. The range-of-motion of the thoracohumeral angles, during shoulder external rotation was significantly less ($p < 0.05$) on the athletes group, athletes also positioned their dominant scapula more retracted and posteriorly tilted. A positive correlation was found between glenohumeral angles and scapular tilt ($r = 0.6777$; $p < 0.05$). Concerning internal rotation; athletes showed significantly greater (highest) thoracohumeral angles ($p < 0.05$). Scapula assumed a position more in retraction and anterior tilt. Based on these findings, it is suggested that differences found in athletes seem to reveal an eventual shoulder adaptation to the throwing mechanics.

Key words: Throwing-shoulder, overhead-athletes, scapular, internal and external rotation.

Introduction

Scapula plays an important role in normal shoulder function. In sports in which demands placed on the shoulder are extremely high, the quality of movements depends on the interaction between scapular and glenohumeral kinematics. How does scapula behave or how much scapula contributes for the axial rotation is not clear yet. The answer to these questions adds important information to understand the shoulder of the overhead throwing athlete in both (and how to behave during); clinical trials and rehabilitation.

The dominant shoulder of overhead throwing athletes consistently shows changes on the rotational range-of-motion (ROM), when compared with non-athletes (Osbaehr et al., 2002, Oyama et al., 2008). Most overhead athletes exhibit an obvious motion disparity, whereby external rotation (ER) is excessive and shoulder internal rotation (IR) is limited when measured at 90° of abduction (Crockett et al., 2002, Meister, 2000, Pieper, 1998, Reagan et al., 2002), nevertheless the total ROM in the dominant arm is preserved. According to Seroyer et al.

(2009) any gain of ER is usually offset by a comparable decrease in IR, resulting in the same total rotational ROM.

However, little is known about the relative contribution of scapular position on the range-of-motion of shoulder external rotation. Changes in scapular position, both dynamic and static, play critical roles in pathologic processes of overhead athletes (Borich et al., 2006, Downar and Sauers, 2005; Borsa et al., 2006). Currently, the scapulothoracic motion's to throwing is one of the least studied and understood entities in the overhead athlete.

Scapular muscle actions allow proper positioning and stability of the scapula while maintaining the glenohumeral center of rotation throughout arm motion. (McMullen and Uhl, 2000). An adequate scapular positioning is believed to be necessary for ideal muscle lengths, force production and (assisting with) glenohumeral joint stability (Burkhart et al., 2003b, Myers et al., 2005, Borich et al., 2006). Muscular imbalances in scapular force couples (action) may result in scapular dyskinesis, abnormal glenohumeral translation or rotator cuff overload. Deviating patterns of ER or the inability to externally rotate the humerus sufficiently may change the scapular kinematics leading to several impairments such as, shoulder impingement, internal rotation deficit among others (Stokdijk et al., 2003).

A few studies (Borich et al., 2006, Oyama et al., 2008) reported asymmetries in the resting scapular position of overhead athletes when comparing the dominant with the non-dominant arm. At rest, the dominant scapula of overhead athletes is positioned more in scapular IR (protraction) and anterior tilt (Borich et al., 2006, Seroyer et al., 2009). It is believed that this anterior tilted position is positively related with the glenohumeral internal rotation deficit, found on most overhead athletes (Borich et al., 2006).

The loss of internal rotation of the throwing shoulder has been referred to as glenohumeral internal rotation deficit (GIRD). The posterior shift in the total arc of motion is considered to be a physiological adaptation of the shoulder joint to throwing. Burkhart et al., (2003a) described glenohumeral internal rotation deficit as an alternative mechanism for primary progression of "internal impingement-like" changes in the shoulder.

Additionally, it is also known that the injury mechanism on overhead athletes is mostly related to the throwing motion and the extreme ROM of ER. (Downar and Sauers, 2005, Borsa et al., 2006).

Thus, the purpose of this study was to analyze the relative contribution of the scapular motion on the extreme active shoulder ROM (ER and IR), in throwing athletes. We hypothesized that at the end-range of shoulder IR athletes would present a scapula in protraction and anterior tilt, and at end-range of shoulder ER athletes would present a scapula in retraction and posterior tilt. The movement with the scapula participation could increase the displacement of the hand range-of-motion, with benefits to hit or spike the ball which should be seen in athletes but not in non-athletes, and considered as an adaptation due to sports practice. This is important in athletes shoulder rehabilitation because, if it presents an adaptation, when restoring the function after an injury, it has to be preserved.

Methods

Participants

Data about each subject was collected and those with a previous history of shoulder surgery or traumatic injury (e.g. dislocation, subluxation) or elbow pain in the last 6 months and athletes with less than 6 years of high level of sports practice (training for at least 5 times a week) were excluded from the study. In addition participants with shoulder or elbow pain in the last 6 months and athletes with less than 6 years of high level of sports practice (training for at least 5 times a week) were also excluded from the study.

Twenty six male subjects were recruited from the community in a voluntary basis and were divided into two study groups. The athletes group was composed by 13 elite team handball players (first division), (height = 1.86 ± 0.03 m; body mass = 84.08 ± 7.6 kg; age = 22.3 ± 3.1 years) and the non-athletes or control group with 13 subjects (height = 1.76 ± 0.05 m; body mass = 72.8 ± 7.2 kg; age = 26.6 ± 4.4 years). Prior to the participation, the purpose of the study and the experimental protocol was explained and subjects signed an informed consent document according to the recommendations of the declaration of Helsinki. Ethical approval for the study was ratified by the Ethics Council of the Faculty of Human Kinetics, Technical University of Lisboa.

Procedures

Motion testing was performed with the Flock of Birds electromagnetic tracking sensors (Ascension Technology, Burlington, Vermont) and Motion Monitor software (Innovative Sports Training, Chicago, IL). Simultaneous tracking of 4 sensors occurred at a sampling rate of 100 Hz per sensor. The accuracy of our system is 1.8 mm for position and 0.15° for orientation.

A four sensor setup was used: the thorax sensor firmly attached to the skin by a double-sided tape over T1; the arm sensor attached by means of a cuff just below the deltoid attachment; and the scapular sensor firmly adjusted on the superior flat surface of the acromion process. A 4th sensor mounted on a hand-held stylus (6.5cm) was used for bony landmark digitalization (Table 1). The digitized bony landmarks (Table 2) were then used to convert the sensor axes to anatomic axes or local coordi-

nate system (LCS) on thorax, scapula and humerus segments, following the recommendations of the International Society of Biomechanics (ISB) (Wu et al., 2005). Using this procedure, sensors axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCSs with tracking sensor motion.

Angular values, expressed in Euler angles, for the humeral motion relative to the thorax (thoracohumeral angles) and to the scapula (scapulohumeral angles) were determined using the ISB (Wu et al., 2005) recommended rotation sequences (y, x', y''): arm elevation, plane of arm elevation and axial rotation. The dependent variables were the 3D kinematic values (protraction, upward rotation and tilting) which were analyzed with reference to the trunk using (y, x', z') (Ludewig et al., 2010). Continuous data were recorded and filtered (Butterworth filter; cut-off = 10Hz) for the thoracohumeral (HRT) and glenohumeral axial rotation (HRs). The end-range position of the humeral external and internal rotation was considered for further analysis.

Table 1. Bony landmarks used on the definition of the local coordinate system of the thorax, scapula and humerus.

Segment	Bony Landmark	Abbrev
Thorax	T8 spinous process	T8
	Xiphoid process of the sternum	PX
	C7 Spinous process	C7
Scapula	Incisura Jugularis of the sternum	IJ
	Angulus acromialis	AA
	Trigonum Spinae Scapulae	TS
Humerus	Angulus Inferior Scapulae	AI
	Epicondylus medialis	EM
	Epicondylus lateralis	EL
	Glenohumeral rotation centre *	GH

Abbrev: Abbreviations. * Estimated by motion recordings, calculating the pivot point of instantaneous helical axes of GH motion (Veeger, 2000, Stokdijk et al., 2000)

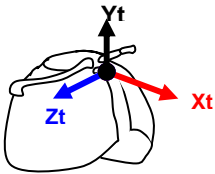
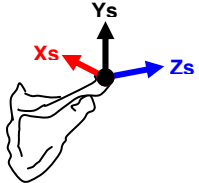
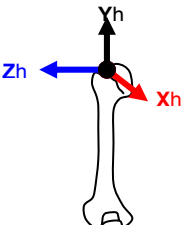
Task

At scapular plane, in a seated position, subjects were instructed to slowly (using a metronome) reach the end-range of humeral external rotation followed by end-range of internal rotation. During this trial the humerus was artificially supported at 90° (without enabling muscle contraction) of shoulder abduction at scapular plane, ensuring position maintenance (Figure 1). The end-range (shoulder internal and external rotation) was self-determined by the subject (subject was not able to go further on the movement) or when examiners observed trunk motion. On the basis of our digitization protocol, the zero point (0°) or neutral rotation was defined as the point when the subject's forearm was perpendicular to the floor.

Data analysis

In this study the dependent variables were humeral and scapular positions of thoracohumeral, glenohumeral angles and protraction, tilt and lateral rotation. All variables were checked for normality (Shapiro & Wilk test) and found to meet criteria for parametric statistics. These were compared between groups using a t-test for independent

Table 2. Definition of the local coordinate systems of the thorax, scapula and humerus, according to Wu et al. (2005).

 <p>THORAX (<i>Right anterolateral view</i>)</p>	<p>Yt: The line connecting the midpoint between XP and T8 and the midpoint between SN and C7 pointing upward</p> <p>Zt: The line perpendicular to the plane formed by SN, C7 and the midpoint between XP and T8 pointing to the right</p> <p>Xt: The common line perpendicular to Zt and Yt-axis pointing forward</p> <p>The origin coincident with SN</p>
 <p>RIGHT SCAPULA (<i>Posterior view</i>)</p>	<p>Ys: The common line perpendicular to Xs and Zs-axis pointing upward</p> <p>Zs: The line connecting RS and AA pointing to AA</p> <p>Xs: The line perpendicular to the plane formed by IA, AA and RS, pointing forward</p> <p>The origin coincident with AA</p>
 <p>RIGHT HUMERUS (<i>Anterior view</i>)</p>	<p>Yh : The line connecting GE and the midpoint of LE and ME, pointing to GH</p> <p>Zh: The common line perpendicular to the Yh and Zh-axis pointing to the right</p> <p>Xh: The line perpendicular to the plane formed by LE, ME and GH pointing forward</p> <p>The origin coincident with GH</p>

samples. Effect size (ES) analysis and probability scores are reported. We used the qualitative assessment (Cohen's *d*) of ES where a small, medium or large change/difference is defined by an ES greater than 0.20, 0.50 or 0.80 respectively (Cohen, 1992). Relationship between thoracohumeral angle and glenohumeral angle and scapular variables were also analyzed by means of bivariate correlations. The level of significance was set at 5% and statistical power at 95%. The Statistical Package for Social Sciences (SPSS) version 20 (Chicago, Illinois) was used to analyze data.

Results

The 3D scapular orientation and humerus axial rotational (range-of-motion) at the end-range of shoulder external and internal rotation are presented in Table 3 and Table 4, respectively. The thoracohumeral angles (humerus angle with respect to thorax, HRt) at the extreme range-of-motion of shoulder ER were significantly smaller in the athletes group. At the end-range of ER, athletes positioned their dominant scapula more in retraction and posterior tilt. In the athletes group a positive correlation ($r = 0.677$, $p < 0.01$) was found between thoracohumeral angle and scapular spinal tilt. A positive correlation ($r = -0.619$, $p = 0.001$) was found between scapular retraction and humeral axial rotation with respect to thorax.

Concerning the extreme range-of-motion of shoulder IR, the athletes group showed a significantly greater range-of-motion thoracohumeral angle, and positioned the dominant scapula more in retraction and anterior tilt. Also in internal rotation we found a negative correlation between lateral rotation of the scapula and thoracohumeral angles ($r = -0.499$, $p = 0.009$). A negative correlation

between spinal tilt and thoracohumeral angle ($r = -0.467$, $p = 0.016$) was also observed.



Figure 1. Set-up for testing humeral axial rotation range-of-motion. Subject at the end-range of active shoulder internal (top) and external rotation (bottom).

Discussion

Shoulder external rotation

During overhead activities, the shoulder, besides having

an adequate rotation, must also have a synchronized motion between humerus, scapula, clavicle and thorax to a proper function (Ludewig et al., 1996, Tokish et al., 2008). In our study, and concerning ER ROM, athletes showed less thoracohumeral (range-of-motion) than non-overhead athletes.

As found in literature (Braun S. et al., 2009, Wilk et al., 2011) athletes tend to develop chronic adaptations which contribute to, or have their origins in the throwing motion. It is hard to conclude if these adaptations are related to a better performance or injury prevention or even if they are responsible for inducing shoulder impairment. In this study, athletes did not follow the external rotation gain found in the literature (Wilk et al., 2011, Tokish et al., 2008, Torres and Gomes, 2009), instead, an external rotation decrease. It is important to notice that these measurements were taken under active condition instead of the usual measurement based on passive condition (McConnell et al., 2012).

The results in external rotation showed also that throwers demonstrated a scapula more in retraction (acromion backwards) when compared with non-throwers. According to literature this seems to be a protective mechanism for the glenohumeral joint (Myers et al., 2005, Ludewig and Reynolds, 2009, Lukasiewicz et al., 1999). In fact, the inability to retract the scapula, appears to impart several negative biomechanical effects on the shoulder structures, including a narrower subacromial space, reduced impingement-free, reduced strength of the glenohumeral muscles (Braun S. et al., 2009). Concerning this, throwers on our study seem to have developed an adaptation towards stability (Forthomme et al., 2008, Borich et al., 2006, Lukasiewicz et al., 1999). During the throwing cycle it is supposed that athletes, such as team handball players, keep their scapula stable while the arm is fastly moved from a full external position to a full internal position. Scapular stabilization could be challenged when the arm motion is very (too) fast. Therefore, an innadequate scapular position at the end-range of glenohumeral motion will lead to shoulder dysfunction and pathology (Werner et al., 2007), such as impingement or dyskinesia.

Excessive motion is required at the shoulder joint during throwing, yet the glenohumeral joint must remain stable to avoid injury. We found that the athletes group showed a more posterior tilted scapula when arm is positioned at the end-range of shoulder external rotation, while the control group showed an anterior tilted scapula. This seems to demonstrate that shoulder adaptation on athletes, while throwing, does not occur only at the

glenohumeral joint, as it is evaluated in sports clinical trial. It is supported by the trunk, where a scapula in retraction and posterior tilt, gives the necessary stability to achieve best performance (Boon and Smith, 2000). This is probably the reason why scapular position relative to humerus and trunk, is so relevant for muscle function. The scapula acts as the common point of attachment of the rotator cuff and primary humeral movers such as the biceps, deltoid and triceps, as well as several scapular stabilizers. Poor position of the scapula can lead to alterations to the relationship between length and tension of each muscle, thus adversely affecting muscle force generation (Myers et al., 2005). An imbalance in shoulder external rotators will lead to alterations in scapular tilt (Ludewig and Cook, 2000, Lukasiewicz et al., 1999).

Clinical trials use passive or active motion. Active motion used is usually a slow motion (McCully et al., 2005), and not simulating the sports practice. Our study used active motion protocol. Although the calibration positioning used was the same proposed by the ISB (Wu et al., 2005) protocol (arm at a side), the testing position was with the arm in an elevated position. The main reason to find more external rotation at non-athletes is possibly the fact that we were evaluating active motion and not passive one (McConnell et al., 2012). Other possible reasons could be muscular skills, for example: an agonist-antagonist relation; or capsular stiffness, which are expected to be different when comparing athletes with non-athletes.

There was positive correlation seen in the athletes group between the thoracohumeral angles and scapular spinal tilt rotation at the extreme position of shoulder external rotation. This seems to show that the posterior scapular tilt follows the increase of the thoracohumeral angle, demonstrating advantages not only towards stability of the shoulder girdle but also for the force-length relationship of the scapulohumeral muscles (Borsa et al., 2003). Concerning this, overhead athletes in our study seem to have developed an adaptation towards stability.

Shoulder internal rotation

In internal rotation, athletes demonstrated a scapula and a humerus that behave as a block when they spin around the diaphysis. The range-of-motion of shoulder axial rotation of the humerus with respect to the scapula (glenohumeral contribution), was not different between athletes and non-athletes. In the athletes group the thoracohumeral IR ROM was higher (~18°). No differences were found in glenohumeral angle. So the higher values of IR range-of-motion seen in athletes seem to be due to an augmented evident scapular contribution to the total IR ROM.

Table 3. Mean (\pm SEM) of scapular and humeral rotations at the end-range of shoulder external rotation (degrees).

Group	Scapular rotations						Humeral rotations			
	Protraction (SyT)		Lateral Rotation (Sxt)		Spinal Tilt (Szt)		Axial rotation w.r.t. Thorax (HRt)		Axial rotation w.r.t. Scapula (HRs)	
	Athletes	Non-Athletes	Athletes	Non-Athletes	Athletes	Non-Athletes	Athletes	Non-Athletes	Athletes	Non-Athletes
Mean	21.4 (1.7)	33.4 (4.3)	35.6 (2.7)	39 (2.8)	10.0 (1.7)	5.8 (2.6)	92.3 (1.8)	113.4 (2.0)	90.2 (4.9)	104.1 (8.3)
ES	-.453		-.166		.260		-.836		-.272	
p	<.05		.14		<.05		<.05		.16	

ES: Effect size; w.r.t.: "with respect to"

Table 4. Mean (\pm SEM) of scapular and humeral rotations at the end-range of shoulder internal rotation (degrees).

Group	Scapular rotations						Humeral rotations			
	Protraction (Syt)		Lateral Rotation (Sxt)		Spinal Tilt (Szt)		Axial rotation w.r.t. Thorax (HRT)		Axial rotation w.r.t. Scapula (HRs)	
	Athletes	Non-Athletes	Athletes	Non-Athletes	Athletes	Non-Athletes	Athletes	Non-Athletes	Athletes	No-Athletes
Mean	32.6 (2.2)	48.0 (1.5)	9.0 (2.6)	12.5 (2.0)	-15.5 (1.9)	-2.9 (.9)	37.7 (2.8)	10.2 (3.6)	30.8 (3.4)	28.7 (4.8)
ES	.749		.205		.757		.762		.069	
p	<.05		.30		<.05		<.05		.73	

ES: Effect size; w.r.t.: "with respect to"

In a more detailed analysis, considering the eventual contribution of the shoulder girdle (in the range-of-motion of IR), athletes seemed to show a scapula in retraction and anterior tilt. Looking for scapular positioning some authors (Borich et al., 2006) found that there is a relationship between glenohumeral internal rotation deficit and abnormal scapular positioning, particularly increased anterior tilt. Also Myers et al (2005) showed in a study with 21 overhead athletes, that at the scapular plane these athletes presented a scapula in upward rotation, protraction and anterior tilt. This protraction pattern accentuates impingement; the situation can be increased with the arm in IR (Borich et al., 2006; Ludewig and Reynolds, 2009; Ludewig et al., 1996).

In our study, differences found in the shoulder girdle seem to reveal an eventual shoulder adaptation in overhead athletes (team handball). In these athletes shoulder axial rotation is followed by scapular retraction. This positioning seems to have advantages to glenohumeral joint stability, particularly at the ER end-range. In IR the scapular positioning in retraction and anterior spinal tilt amplifies the shoulder axial rotation motion. This seems why overhead athletes keep stability, achieving more range-of-motion on behalf of the scapula, without losing stability (Borich et al., 2006, Oyama et al., 2008, Myers et al., 2005).

As mentioned before, and when considering shoulder joint adaptations seen in literature concerning internal rotation (Dwelly et al., 2009, Torres and Gomes, 2009), we cannot be sure they are exactly towards less internal rotation. These studies use goniometry where the scapula is fixed not allowing the subject to complete the total range-of-motion (Boon and Smith, 2000). As seen previously, scapular contribution is crucial for a complete motion. Blocking the scapular movement will affect total ROM. If the scapular movement is blocked, the total range-of-motion will be affected. This is why, knowledge of joint ROM and speeds of movement along with joint forces and moments will provide a scientific basis for improved and rehabilitative protocols for throwers.

So in conclusion, concerning shoulder external rotation the athletes group showed less thoracohumeral range-of-motion than non-overhead athletes. Athletes also presented a scapula in retraction and posterior tilt. Considering internal rotation, athletes group demonstrated higher thoracohumeral range-of-motion, when compared with non-athletes, but no differences were found in scapulothoracic range-of-motion, which means that higher values of internal rotation seen in athletes seem to be due to an evident scapular contribution. Also in internal rota-

tion, athletes seemed to show a scapula in retraction and anterior tilt. This scapular position amplifies the shoulder axial rotation motion, (Borich et al., 2006) and could be the reason why overhead athletes seem to keep stability, achieving more range-of-motion. Taking into account these results, differences found in athletes (team handball) concerning shoulder girdle behavior seem to reveal an eventual shoulder adaptation.

Conclusion

Current study provides clinicians with an understanding of the effects of sport related adaptations on healthy athletes throwing shoulder. A specific scapular positioning seems to be related to sports practice and also protective to the throwing shoulder, which is a fundamental outcome to the throwers evaluation at clinic.

As a limitation of this study we would include possible skin artifacts, especially at the arm sensor. To avoid this situation we used a sensor mounted on a tiny cuff adjusted to the arm just below the deltoid attachment, trying to ensure the sensor position towards the skin. Subjects were asked to actively reach end-range. The end point for the active motion was determined by patient comfort and by capsular end-feel similarly to goniometric procedures (Boon and Smith, 2000).

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Key points

- In external rotation end-range, athletes positioned their scapula more in retraction and posterior tilt.
- In internal rotation end-range, athletes positioned their scapula more in retraction and anterior tilt.
- Results seem to reveal a sport-related shoulder adaptation.

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